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(54) **METHOD AND APPARATUS FOR HANDLING IN-DEVICE CO-EXISTENCE INTERFERENCE IN A WIRELESS COMMUNICATION ENVIRONMENT**

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(Continued)

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CPC *H04W 72/0446* (2013.01); *H04B 1/109* (2013.01); *H04J 3/1694* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H04B 1/109; H04B 15/00; H04B 15/02; H04J 3/1694; H04W 16/14; H04W 36/28;
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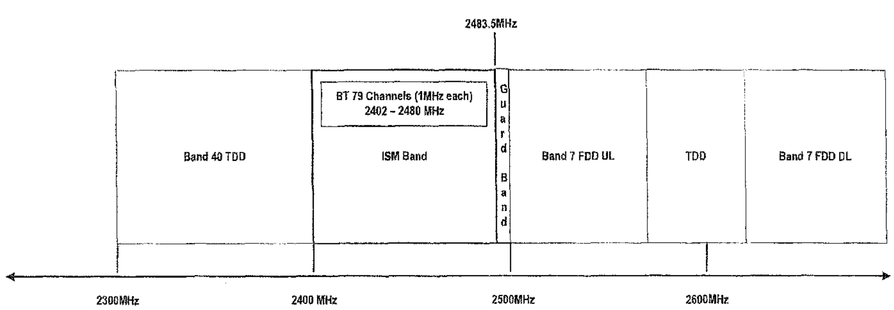
Primary Examiner — Jamal Javaid
Assistant Examiner — Rose Clark

(57) **ABSTRACT**

The present disclosure provides a method and apparatus of handling in-device co-existence interference in a wireless communication environment. In one embodiment, a method includes detecting in-device co-existence interference between a LTE module and an ISM module in user equipment. The method further includes identifying subframes and corresponding HARQ processes in a set of subframes allocated to the LTE module which are affected by the ISM module operation. Additionally, the method includes reserving the remaining subframes and corresponding HARQ processes in the set of subframes for the LTE module
(Continued)



operation. Furthermore, the method includes indicating to a base station that the remaining subframes and the corresponding HARQ processes are reserved for the LTE module operation to resolve the in-device co-existence interference. Moreover, the method includes receiving scheduling pattern indicating subframes and corresponding HARQ processes reserved for the LTE operation or derived DRX parameters from the base station based on the indication.

16 Claims, 6 Drawing Sheets

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H04W 72/12	(2009.01)
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H04W 72/08	(2009.01)
H04L 1/18	(2006.01)
H04W 76/28	(2018.01)
H04W 88/06	(2009.01)

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CPC ***H04L 1/1812*** (2013.01); ***H04L 1/1861*** (2013.01); ***H04W 72/082*** (2013.01); ***H04W 72/1215*** (2013.01); ***H04W 76/28*** (2018.02); *H04W 88/06* (2013.01)

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CPC H04W 52/0238; H04W 72/082; H04W 72/1215; H04W 76/00; H04W 76/02; H04W 76/025; H04W 76/04; H04W 76/048; H04W 88/06; H04W 24/04; H04W 72/0446
See application file for complete search history.

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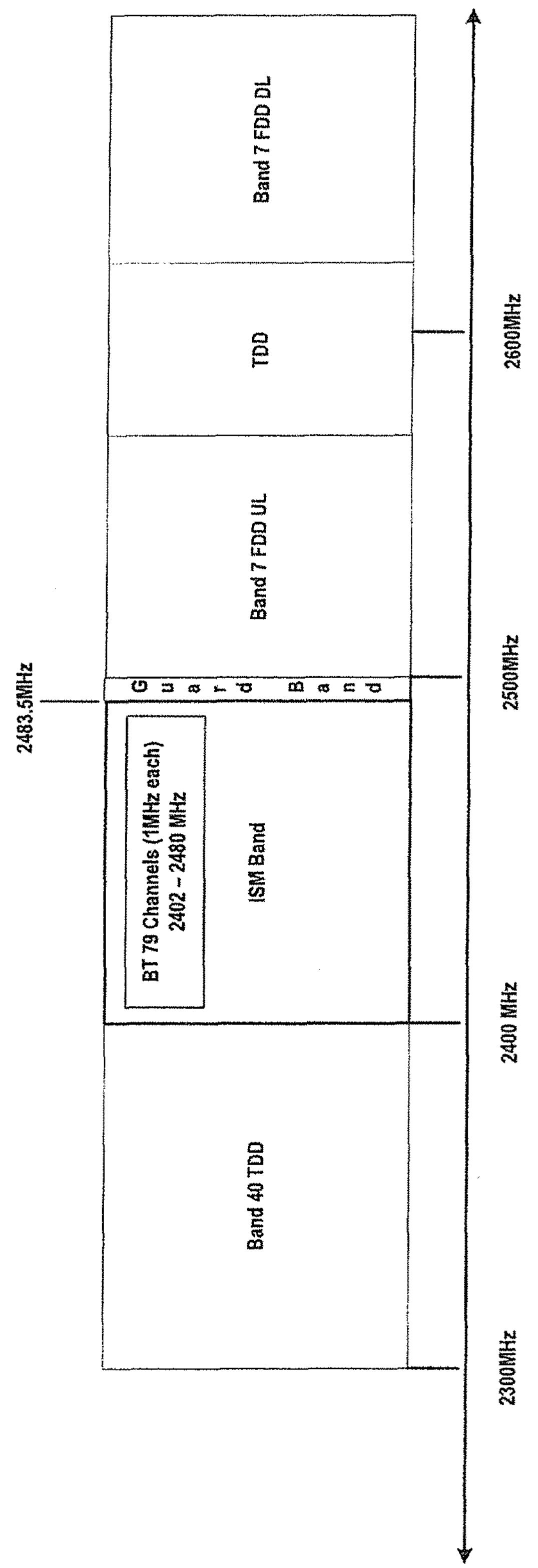
Band 7 FDD DL
TDD
Band 7 FDD UL
Guard Band
BT 79 Channels (1MHz each)
2402 - 2480 MHz
ISM Band
Band 40 TDD
2483.5MHz
2600MHz
2500MHz
2400 MHz
2300MHz

FIGURE 1A

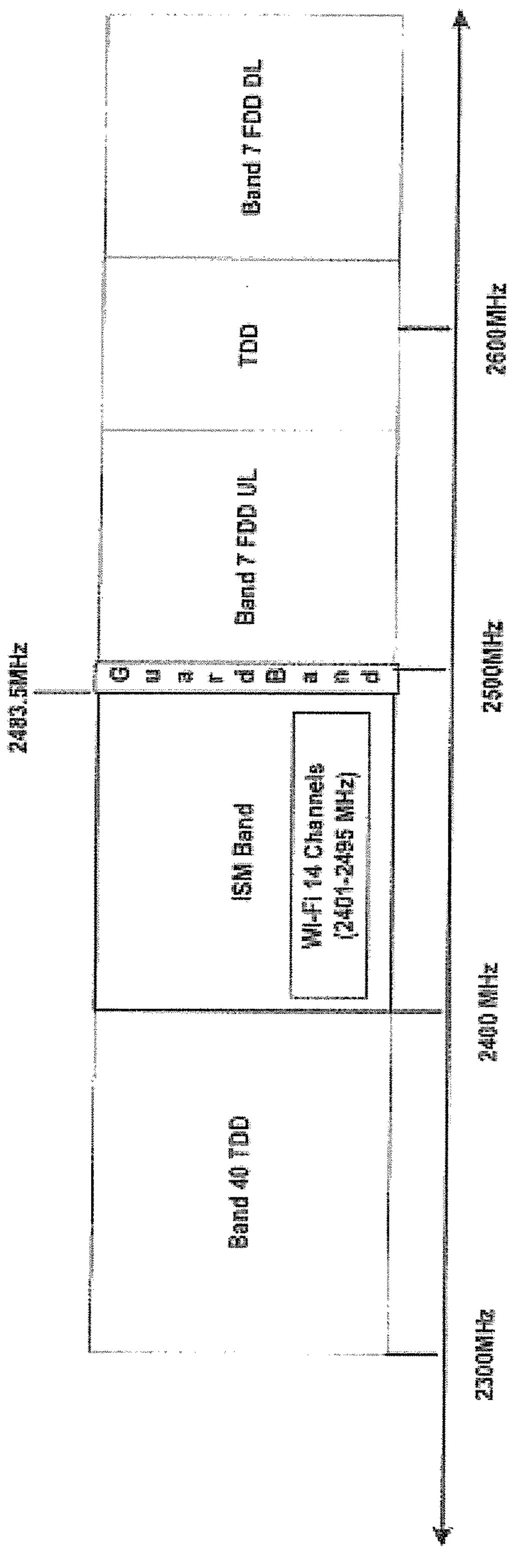
Band 7 FDD DL
TDD
Band 7 FDD UL
Guard Band
ISM Band
Wi-Fi 14 Channels
(2401-2495 MHz)
Band 40 TDD
2483.5MHz
2300MHz
2400 MHz
2500MHz
2600MHz

FIGURE 1B

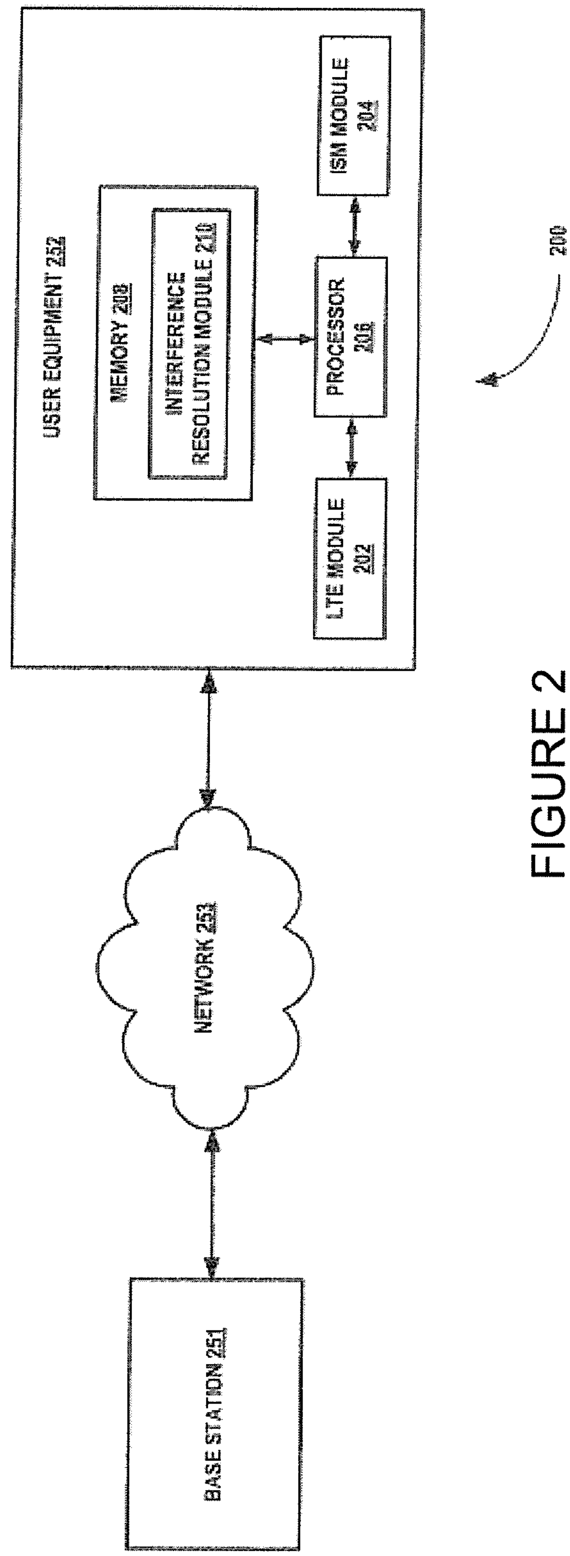
USER EQUIPMENT 252
MEMORY 208
INTERFERENCE RESOLUTION MODULE 210
PROCESSOR 206
ISM MODULE 204
LTE MODULE 202
200
NETWORK 253
BASE STATION 251

FIGURE 2

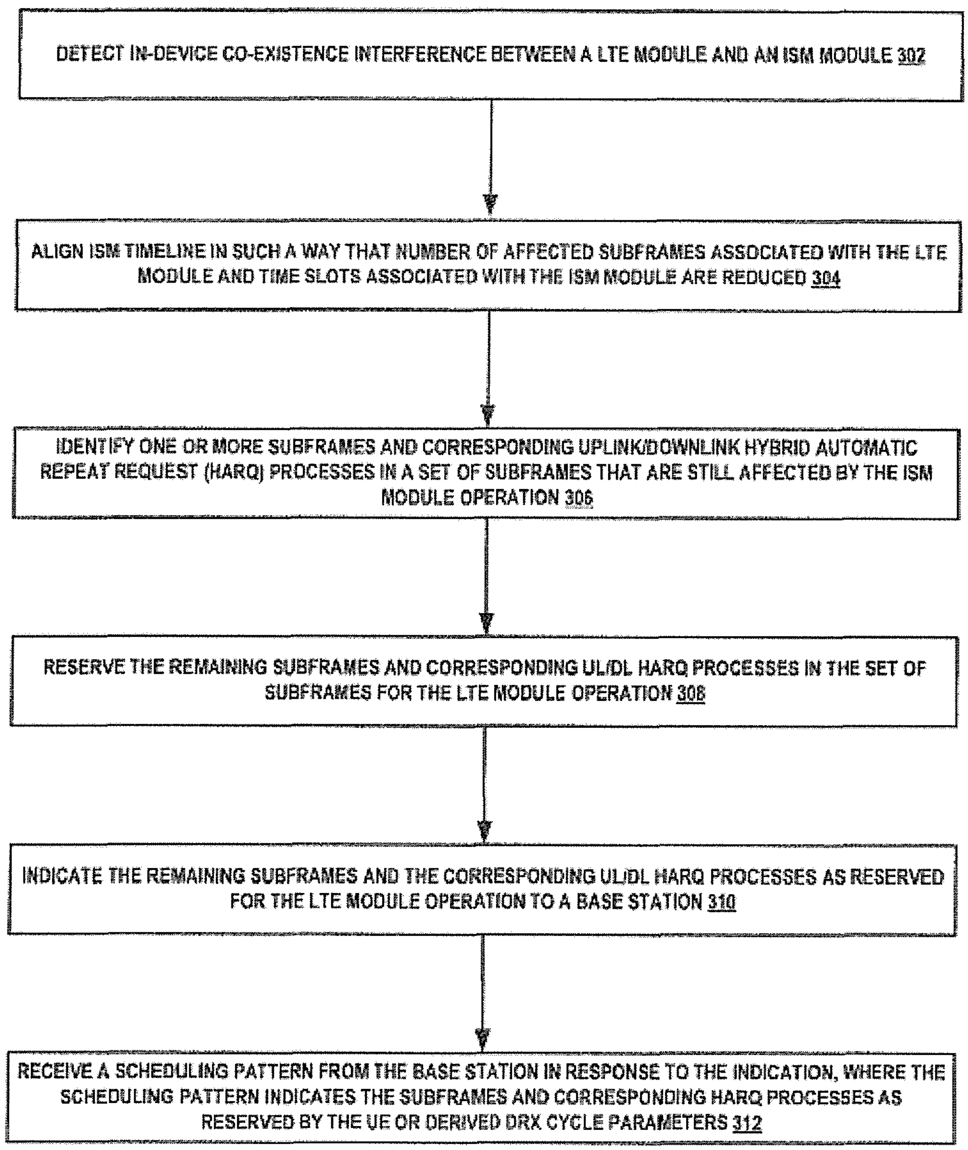
DETECT IN-DEVICE CO-EXISTENCE INTERFERENCE BETWEEN A LTE MODULE AND AN ISM MODULE 302
ALIGN ISM TIMELINE IN SUCH A WAY THAT NUMBER OF AFFECTED SUBFRAMES ASSOCIATED WITH THE LTE MODULE AND TIME SLOTS ASSOCIATED WITH THE ISM MODULE ARE REDUCED 304
IDENTIFY ONE OR MORE SUBFRAMES AND CORRESPONDING UPLINK/DOWNLINK HYBRID AUTOMATIC REPEAT REQUEST (HARQ) PROCESSES IN A SET OF SUBFRAMES THAT ARE STILL AFFECTED BY THE ISM MODULE OPERATION 306
RESERVE THE REMAINING SUBFRAMES AND CORRESPONDING UL/DL HARQ PROCESSES IN THE SET OF SUBFRAMES FOR THE LTE MODULE OPERATION 308
INDICATE THE REMAINING SUBFRAMES AND THE CORRESPONDING UL/DL HARQ PROCESSES AS RESERVED FOR THE LTE MODULE OPERATION TO A BASE STATION 310
RECEIVE A SCHEDULING PATTERN FROM THE BASE STATION IN RESPONSE TO THE INDICATION, WHERE THE SCHEDULING PATTERN INDICATES THE SUBFRAMES AND CORRESPONDING HARQ PROCESSES AS RESERVED BY THE UE OR DERIVED DRX CYCLE PARAMETERS 312

FIGURE 3

300

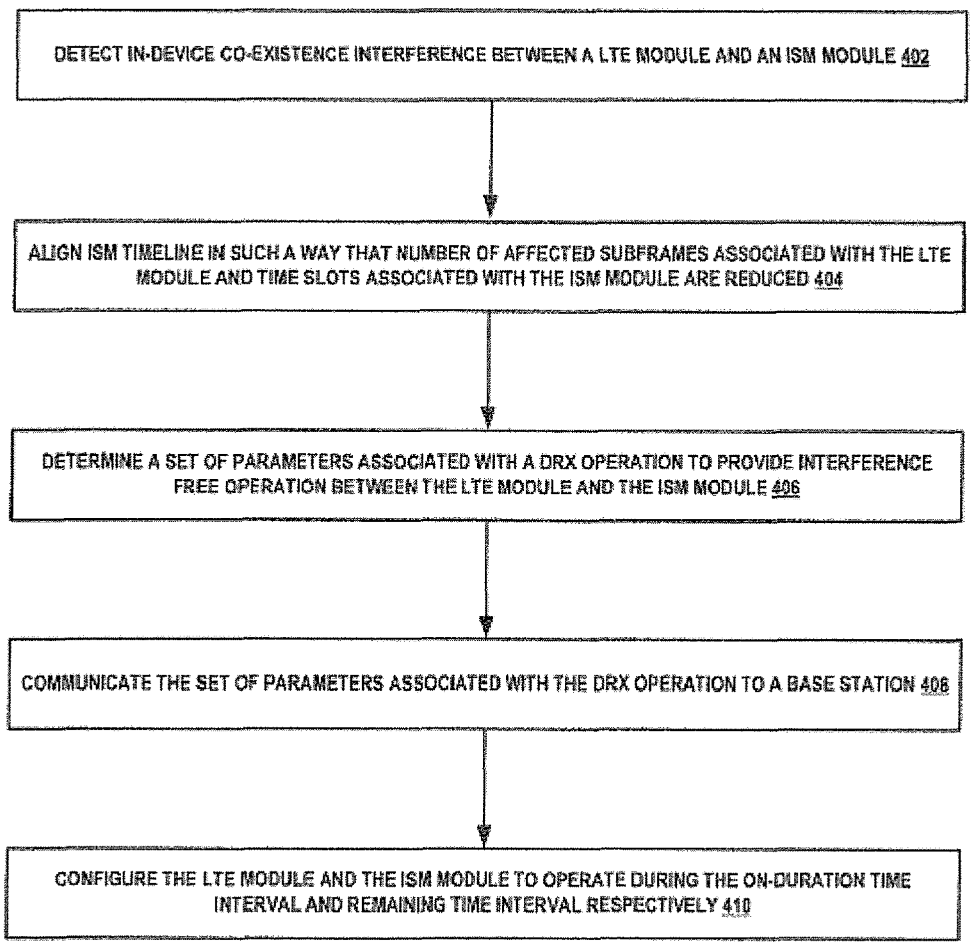
DETECT IN-DEVICE CO-EXISTENCE INTERFERENCE BETWEEN A LTE MODULE AND AN ISM MODULE 402
ALIGN ISM TIMELINE IN SUCH A WAY THAT NUMBER OF AFFECTED SUBFRAMES ASSOCIATED WITH THE LTE MODULE AND TIME SLOTS ASSOCIATED WITH THE ISM MODULE ARE REDUCED 404
DETERMINE A SET OF PARAMETERS ASSOCIATED WITH A DRX OPERATION TO PROVIDE INTERFERENCE FREE OPERATION BETWEEN THE LTE MODULE AND THE ISM MODULE 406
COMMUNICATE THE SET OF PARAMETERS ASSOCIATED WITH THE DRX OPERATION TO A BASE STATION 408
CONFIGURE THE LTE MODULE AND THE ISM MODULE TO OPERATE DURING THE ON-DURATION TIME INTERVAL AND REMAINING TIME INTERVAL RESPECTIVELY 410

FIGURE 4

400

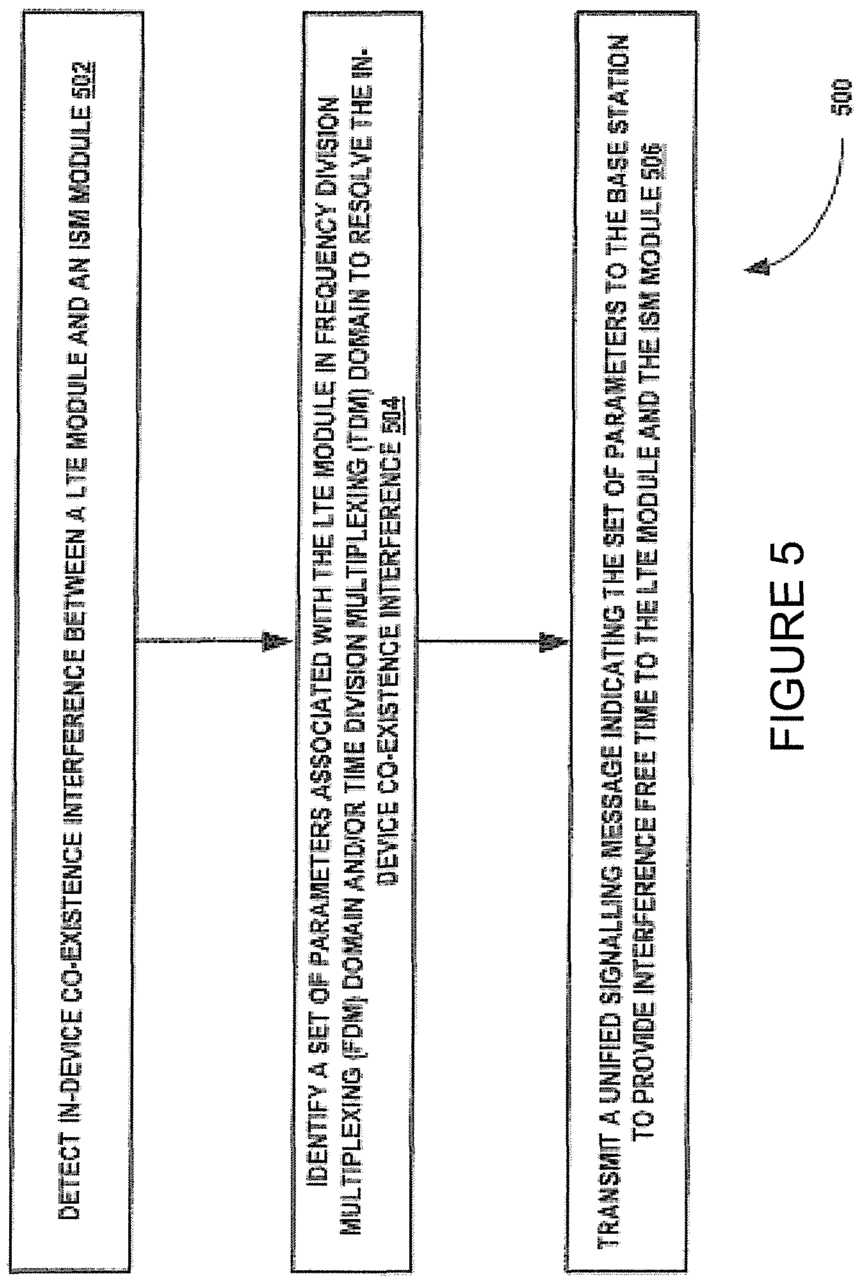
DETECT IN-DEVICE CO-EXISTENCE INTERFERENCE BETWEEN A LTE MODULE AND AN ISM MODULE 502
IDENTIFY A SET OF PARAMETERS ASSOCIATED WITH THE LTE MODULE IN FREQUENCY DIVISION MULTIPLEXING (FDM) DOMAIN AND/OR TIME DIVISION MULTIPLEXING (TDM) DOMAIN TO RESOLVE THE IN-DEVICE CO-EXISTENCE INTERFERENCE 504
TRANSMIT A UNIFIED SIGNALLING MESSAGE INDICATING THE SET OF PARAMETERS TO THE BASE STATION TO PROVIDE INTERFERENCE FREE TIME TO THE LTE MODULE AND THE ISM MODULE 506
500

FIGURE 5

METHOD AND APPARATUS FOR HANDLING IN-DEVICE CO-EXISTENCE INTERFERENCE IN A WIRELESS COMMUNICATION ENVIRONMENT

CROSS-REFERENCE TO RELATED APPLICATION(S) AND CLAIM OF PRIORITY

The present application is a continuation of U.S. Non-Provisional patent application Ser. No. 13/877,834 filed Apr. 4, 2013 and entitled "METHOD AND APPARATUS FOR HANDLING IN-DEVICE CO-EXISTENCE INTERFERENCE IN A WIRELESS COMMUNICATION ENVIRONMENT," which is a national stage filing of Patent Cooperation Treaty Patent Application No. PCT/KR2011/007332 filed Oct. 4, 2011 and entitled "METHOD AND APPARATUS FOR HANDLING IN-DEVICE CO-EXISTENCE INTERFERENCE IN A WIRELESS COMMUNICATION ENVIRONMENT," which claims priority to Indian Patent Application No. 2939/CHE/2010 filed Oct. 4, 2010 and entitled "SYSTEM AND METHOD FOR HANDLING IN-DEVICE CO-EXISTENCE INTERFERENCE BETWEEN LTE AND ISM TECHNOLOGIES." The content of the above-identified patent documents is incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to the field of wireless communication system, and more particularly relates to handling in-device co-existence interference in a wireless communication environment.

BACKGROUND

Coexistence of LTE with ISM (Bluetooth®, Wi-Fi®, and the like) band technologies and global navigation satellite system (GNSS) technology is necessary to be provided as these are becoming very common combinations in mobile handsets. Each of these technologies is developed by different group to serve a specific purpose. Characteristics of each of these technologies are different. They operate in different frequencies, have different access mechanism, have different frame structure, and peak transmit power.

When all these technologies operate simultaneously in an adjacent band, (small separation, e.g., <20 MHz) usually 50 dB isolation is required. However, small form factor of the UE provides only 10-30 dB isolation. As a result, the transmitter of one radio severely affects the receiver of another radio. For example, a small form factor of the UE may pose great challenge of interference from transmission of ISM technology to the receiver of cellular technologies such as LTE or WiMAX. Similarly, the transmitter of cellular technology may cause severe interference to the ISM receiver. The main cause of in-device co-existence issues may be because of receiver blocking due to limited dynamic range of power amplifier, Analogue to Digital converter and out of band emission due to imperfect filtering.

SUMMARY

The present disclosure provides a method and apparatus of handling in-device co-existence interference in a wireless communication environment. In one embodiment, a method includes detecting in-device co-existence interference between a LTE module and an ISM module in user equipment. The method further includes identifying subframes and corresponding HARQ processes in a set of subframes allocated to the LTE module which are affected by the ISM module operation. Additionally, the method includes reserving the remaining subframes and corresponding HARQ processes in the set of subframes for the LTE module operation. Furthermore, the method includes indicating to a base station that the remaining subframes and the corresponding HARQ processes are reserved for the LTE module operation to resolve the in-device co-existence interference. Moreover, the method includes receiving scheduling pattern indicating subframes and corresponding HARQ processes reserved for the LTE operation or derived DRX parameters from the base station based on the indication.

DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a schematic diagram illustrating separation between LTE and Bluetooth® channels, in the context of the disclosure.

FIG. **1**B is a schematic diagram illustrating separation between LTE and Wi-Fi® channels, in the context of the disclosure.

FIG. **2** illustrates a block diagram of wireless communication system for handling in-device co-existence interference between a LTE module and an ISM module in user equipment, according to one embodiment.

FIG. **3** is a process flowchart illustrating an exemplary method of handling in-device co-existence interference between the LTE module and the ISM module of the user equipment, according to one embodiment.

FIG. **4** is a process flowchart illustrating an exemplary method of handling in-device co-existence interference between the LTE module and the ISM module of the user equipment, according to another embodiment.

FIG. **5** is a process flowchart illustrating an exemplary method of handling in-device co-existence interference between the LTE module and the ISM module of the user equipment, according to yet another embodiment.

The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

DETAILED DESCRIPTION

[Technical Problem]

LTE Coexistence with Bluetooth®

A LTE band 7 UL and Bluetooth® band are separated by 20 MHz frequency band. The band 7 is FDD band and hence the LTE receiver is not affected by the Bluetooth® transmitter whereas the LTE transmitter can affect the Bluetooth® receiver. Also, there is very negligible separation of 2 MHz between LTE band 40 (TDD band) and the Bluetooth® frequency band. Therefore, it is not possible to discontinue using higher portion of LTE band 40 in case of coexistence. FIG. **1**A is a schematic diagram illustrating separation between LTE and Bluetooth® channels.

LTE Co-existence with Wi-Fi®

There are 14 channels demarcated in an ISM band for a Wi-Fi® operation. Each channel is separated from other channel by 5 MHz with an exception of channel number 14 which is separated by 12 MHz. The channel **1** starts with 2401 MHz and hence there is almost no separation between LTE band 40 and Wi-Fi. Channel **14** of Wi-Fi® ends at 2495 MHz so theoretically only 5 MHz separation is available between the LTE band 7 and the Wi-Fi®. Different countries have different policies for number of allowed channels of the

Wi-Fi®. Currently, many countries allow only channel **1** to **13** whereas Japan allows usage of channel number **14** only for IEEE 802.11b based communication. This suggest even though in theory only 5 MHz separation is available between the Wi-Fi and the LTE band 7 but in practice at least 17 MHz is available. FIG. **1**B is a schematic diagram illustrating separation between LTE and Wi-Fi® channels.

[Technical Solution]

A method of handling an in-device co-existence interference in a user equipment, comprising: detecting an in-device co-existence interference between a LTE module and an ISM module in a user equipment; identifying one or more subframes and corresponding HARQ processes in a set of subframes allocated to the LTE module which are affected by the ISM module operation; reserving the remaining subframes and corresponding HARQ processes in the set of subframes for the LTE module operation; and indicating, to a base station, that the remaining subframes and the corresponding HARQ processes in the set of subframes are reserved for the LTE module operation to resolve in-device co-existence interference between the LTE module and the ISM module.

An apparatus comprising: a processor; and memory coupled to the processor, wherein the memory includes an interference resolution module configured for: detecting an in-device co-existence interference between a LTE module and an ISM module; identifying one or more subframes and corresponding HARQ processes in a set of subframes allocated to the LTE module which are affected by the ISM module operation; reserving the remaining subframes and corresponding HARQ processes in the set of subframes for the LTE module operation; and indicating, to a base station, that the remaining subframes and the corresponding HARQ processes in the set of subframes are reserved for the LTE module operation to resolve in-device co-existence interference between the LTE module and the ISM module.

A method of handling an in-device co-existence interference in a user equipment, comprising: detecting an in-device co-existence interference between a LTE module and an ISM module of a user equipment; determining a set of parameters associated with a DRX operation to cause interference free operation of the LTE module and the ISM module; and communicating the set of parameters associated with the DRX operation to a base station in a wireless network.

An apparatus comprising: a processor; and memory coupled to the processor, wherein the memory includes an interference resolution module configured for: detecting an in-device co-existence interference between a LTE module and an ISM module; determining a set of parameters associated with a DRX operation to cause interference free operation between the LTE module and the ISM module; and communicating the set of parameters associated with the DRX operation to a base station in a wireless network.

A method of handling an in-device co-existence interference in a user equipment comprising: detecting an in-device co-existence interference between a LTE module and an ISM module of a user equipment; identifying a set of parameters associated with the LTE module in at least one of frequency domain and time domain to resolve the in-device co-existence interference; and transmitting a unified signaling message indicating the set of parameters such that the base station schedules data to the user equipment based on the set of parameters to provide interference free time to the LTE module and the ISM module.

An apparatus comprising: a processor; and memory coupled to the processor, wherein the memory includes an interference resolution module configured for: detecting an in-device co-existence interference between a LTE module and an ISM module; identifying a set of parameters associated with the LTE module in at least one of frequency domain and time domain to resolve the in-device co-existence interference; and transmitting a unified signaling message indicating the set of parameters to a base station such that the base station schedules data to the user equipment based on the set of parameters to provide interference free time to the LTE module and the ISM module.

[Advantageous Effects]

The present disclosure provides a method and apparatus of handling in-device co-existence interference in a wireless communication environment

The present disclosure provides a method and apparatus for handling in-device co-existence interference in a user equipment. In the following detailed description of the embodiments of the subject matter of this disclosure, reference is made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration specific embodiments in which the subject matter of this disclosure may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the subject matter of this disclosure, and it is to be understood that other embodiments may be utilized and that changes may be made without departing from the scope of the present disclosure. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present disclosure is defined only by the appended claims.

FIG. **2** illustrates a block diagram of wireless communication system **200** for handling in-device co-existence interference between a LTE module and an ISM module in user equipment, according to one embodiment. In FIG. **2**, the wireless communication system **200** includes a base station (e.g., eNB) **250** and a user equipment (UE) **251** connected via a wireless network (e.g., LTE network) **253**. The user equipment **252** includes a LTE module **202**, an ISM module **204**, a processor **206**, and memory **208**. The memory **208** includes an interference resolution module **210** stored in the form of instructions, that when executed by the processor **206**, result in handling in-device co-existence interference between the LTE module **202** and the ISM module **204**.

Consider that, the LTE module **202** and the ISM module **204** are ON and the interference resolution module **210** has detected that the LTE module **202** interferes with the operation of the ISM module **204**. In such a case, the interference resolution module **210** ensures interference free operation of the LTE module **202** and the ISM module **204** by performing one of the methods described in FIGS. **3** to **5**.

FIG. **3** is a process flowchart **300** illustrating an exemplary method of handling in-device co-existence interference between the LTE module **202** and the ISM module **204** of the user equipment (UE) **252**, according to one embodiment. At step **302**, in-device co-existence interference between the LTE module **202** and the ISM module **204** is detected. For example, the interference resolution module **210** may determine that the LTE module operation causes interference to the ISM module operation or get interfered by the ISM module operation. At step **304**, the ISM timeline is aligned in such a way that number of affected subframes associated with the LTE module **202** and time slots associated with the ISM module **204** are reduced as much as possible to reduce the interference caused the LTE module **202** or the ISM module **204**. If the interference still persists, then the interference resolution module **210** performs steps described below.

At step **306**, one or more subframes and corresponding uplink/downlink hybrid automatic repeat request (HARQ) processes in a set of subframes that still interfere with or interfered by the ISM module operation are identified. At step **308**, remaining subframes and corresponding UL/DL HARQ processes in the set of subframes are reserved for the LTE module operation. In step **310**, the remaining subframes and the corresponding UL/DL HARQ processes are indicated as reserved for the LTE module operation to the base station **251** in a gap pattern. The remaining subframes and the corresponding UL/DL HARQ processes are indicated to the base station **251** when the UE **252** has received a message indicating whether the wireless network supports reporting of in-device co-existence interference at the UE **252**.

In one embodiment, the remaining subframes and the corresponding UL/DL HARQ processes are represented and indicated to the base station **251** in a bitmap based gap pattern. The length of bitmap based gap pattern depends on LTE TDD configuration or a FDD mode of operation. For example, the length of bitmap for FDD is '8' and 'UL-DL configuration' in TDD domain. In another embodiment, the remaining subframes and the corresponding UL/DL HARQ processes are represented and indicated in terms of DRX parameters such as length of DRX cycle, on-duration timer interval and so on. In these embodiments, the DRX parameters or bitmap information is communicated in a message.

The message can be a new message (hereinafter referred to as in-device co-existence interference indication or IDC_IND) or existing LTE message such as measurement report. A new measurement trigger e.g., C**1** can be introduced if the measurement report is used. When measurement reports are used for creating gap pattern, the measurement configuration related to the interference reporting may include specific measurement reporting events which clearly identify interference reporting. These events may be pre-configured or dynamically configured by the wireless communication network. The threshold for reporting these events can be based upon on RSRP, RSSI RSRP, SINR or any other general measurement in the UE **252**. These thresholds are specified in the measurement configuration from the wireless communication network **253** to the UE **252**.

The reserved subframes and UL/DL HARQ processes are indicated to the base station **251** to accommodate ISM/GNSS traffic during the identified subframes and the corresponding UL/DL HARQ processes. Based on the indication, the base station **251** is aware that there is in-device co-existence interference between the LTE module **202** and the ISM module **204** at the UE **251**. Accordingly, the base station **251** incorporates the bitmap information/DRX parameters in scheduling UL/DL data to the UE **252**.

At step **312**, a scheduling pattern is received from the base station **251** in response to the indication. The scheduling pattern indicates reserved subframes and corresponding HARQ processes as determined by the UE **252** in a bitmap or derived DRX parameters. Alternatively, the base station **251** may indicate modified subframes and DL/UL HARQ processes via a modified bitmap or DRX parameters. For example, when the ISM module **204** is a Bluetooth® transceiver, the base station **251** provides at least one subframe to allow at least a pair of clean Bluetooth® Tx/Rx instances in each Bluetooth® interval and other subframes to the LTE module **202**. It means that UE **252** can assume that the base station **251** restricts itself to DL allocation/UL grants inside the scheduling pattern. Accordingly, the scheduling pattern is applied to resolve in-device co-existence interference at the UE **252**. Thus, in this manner, the above process provides interference free time to the LTE module **202** and the ISM module **204**.

FIG. **4** is a process flowchart **400** illustrating an exemplary method of handling in-device co-existence interference between the LTE module **202** and the ISM module **204** of the UE **252**, according to another embodiment. At step **402**, in-device co-existence interference between the LTE module **202** and the ISM module **204** is detected. At step **404**, the ISM timeline is aligned in such a way that number of affected subframes associated with the LTE module **202** and time slots associated with the ISM module **204** are reduced as much as possible.

At step **406**, a set of parameters associated with DRX operation are determined to resolve in-device co-existence interference between the LTE module **202** and the ISM module **204**. The set of parameters includes on-duration timer, inactivity timer, retransmission timer, and length of the DRX cycle. The values of parameters depend on the use case and the scenario of co-existence seen by the UE **252** at the moment and the ISM module activity it expects. At step **408**, the set of parameters associated with the DRX operation is communicated to the base station **251**. For example, the set of parameters are communicated in a measurement report (e.g., C**1** measurement report) or any other message. In some embodiments, the set of parameters are transmitted to the base station **251** when the UE **252** has received a message indicating whether the wireless network supports reporting of in-device co-existence interference at the UE **252**. Accordingly, the base station **251** configures DRX cycle parameters based on the set of parameters associated with the DRX cycle.

At step **410**, the LTE module **202** and the ISM module **204** are configured to operate during the on-duration time interval and remaining time interval (DRX cycle—on-duration timer) respectively. In some embodiments, the in-activity timer is set to a value zero till the in-device co-existence interference exists between the LTE module **202** and the ISM module **204**. In these embodiments, activities of the LTE module **202** are suspended during the remaining time interval of the DRX cycle (e.g., when the in-activity timer is running). For example, the LTE module activity such as adaptive/non-adaptive UL retransmissions, DL retransmissions, service request, and contention resolution is suspended during the in-activity timer. In one embodiment, the LTE module activities are suspended by setting the retransmission timer to a value zero till the in-device co-existence interference exists between the LTE module **202** and the ISM module **204**. Thus, the ISM module activity is allowed without interference when the in-activity timer is running.

The gap patterns discussed above tries to make either LTE module **202** or ISM module **204** to be operational at any given point of time. However, the gap patterns may be designed in such a way that transmission and/or reception of LTE signals are synchronized with transmission and/or reception of ISM signals. It may also be possible that a short duration transmission or reception in LTE signals may not affect the reception or transmission of the ISM signals and vice a versa because of strong channel coding available in the corresponding technology and hence can be allowed. Therefore, the gap design can consider the above said flexibility available due to channel coding. Such autonomous UE behavior of determining as when to operate the LTE module and/or the ISM module for creating gap pattern for some rare situation helps in reducing the design of many gap patterns. This occasional UE autonomous behavior is needed for effective handling of in-device co-existence interference. The UE **252** may decide autonomously to perform UL/DL activity to protect small infrequent but important events of other technology and hence create autonomous gaps keeping the minimal BLER requirements for LTE transmission and reception.

In LTE measurement gaps are supported to help UE perform inter-frequency measurement. In another embodiment measurement gap can be used to provide the desired TDM solution to solve for in-device co-existence interference with small change in values of the measurement gap related parameters.

FIG. **5** is a process flowchart **500** illustrating an exemplary method of handling in-device co-existence interference between the LTE module **202** and the ISM module **204** of the UE **252**, according to yet another embodiment. At step **502**, in-device co-existence interference between the LTE module **202** and the ISM module **204** is detected. At step **504**, a set of parameters associated with the LTE module **202** in Frequency Division Multiplexing (FDM) domain and/or Time Division Multiplexing (TDM) domain is identified to resolve the in-device co-existence interference. In FDM domain, the set of parameters includes one or more frequencies in the LTE band which cause interference to the ISM module **204** or are affected by the ISM module **204**. In TDM domain, the set of parameters includes DRX cycle parameters and/or reserved HARQ process values (e.g. bitmap pattern) associated with the LTE module operation. For example, the DRX cycle parameters include on-duration timer value, length of DRX cycle, re-transmission timer value, and inactivity timer value. The HARQ process values includes one or more subframes and corresponding HARQ processes in a set of subframes which do not contribute to the in-device co-existence interference.

At step **506**, a unified signaling message indicating the set of parameters is transmitted to the base station **251** to provide interference free time to the LTE module **202** and the ISM module **204**. A unified signaling is a mechanism in which FDM and/or TDM solution related parameters are communicated simultaneously to the base station **251**. The unified signaling message is transmitted to the base station **251** only when the UE **252** is aware that the wireless network supports reporting of in-device co-existence interference detected at the UE **252**. Also, the unified signaling message indicates whether the UE **252** prefers a TDM based solution or a FDM based solution to resolve the in-device co-existence interference.

Accordingly, the base station **251** schedules data to the UE **252** in TDM domain or selects the FDM domain solution based on the set of parameters. If the TDM solution is selected, the UE **252** receives a scheduling pattern from the base station **251** in response to the set of parameters associated with the TDM domain. If the FDM solution is selected, then the UE **252** may be notified through a message indicating that a FDM solution is selected to resolve in-device co-existence interference, where the message may include a handover command to handover a wireless connection from one component carrier (e.g., Primary cell) to another or a deactivation command to deactivate the affected component carrier(s) (e.g., Secondary cells). The FDM solution refers to the base station **251** decision to prepare the UE **252** and the wireless communication network **253** for inter-frequency handover.

The UE **252** is also configured to detect end of in-device co-existence interference between the LTE module **202** and the ISM module **204**. When there is no interference, the UE **252** communicates the end of in-device co-existence interference between the LTE module **202** and the ISM module **204** via a unified signaling message, a measurement report, a radio resource connection (RRC) message, or a new message. In an example, the unified signaling message can also have enable and disable kind of signaling. The 'signal enable' is used when in-device co-existence interference is detected, whereas the 'signal disable' is used when the in-device co-existence interference is no more present.

In LTE, in the case of UL scheduling, there is a considerable time from the instance a grant is received on a PDCCH and the corresponding UL transmission is carried over the air interface. An UL grant received in TTI 'n' is applicable for TTI 'n+k' where 'k' is 4 in case of FDD and depends on 'UL-DL Configuration' and varies from one another. Depending on the value of 'k', the UE has the prior knowledge of UL transmission.

In one embodiment of the present disclosure, the prior knowledge of UL transmission can be exploited in determining the gap pattern. So it is possible that the UE **252** may not send the suggested bit pattern for UL and the base station **251** can schedule the UE **252** in any of the UL TTI and the UE **252** uses the knowledge of frame relevance to turn ON/OFF ISM module activity.

In the LTE DL, data assignments received in TTI 'n' are applicable in same TTI, i.e., TTI 'n'. At most, first 3 symbols of a sub frame are used for PDCCH and the PDCCH decoding based on the corresponding UE RNTI reveals if the data is for the UE **251**. In this case, if the UE **252** can decode the PDCCH quick enough well before the end of the subframe, the UE **252** have good enough time to activate the ISM radio if the UE **252** figures out that there is no data in that particular TTI for it.

Alternatively, the UE **252** can activate the ISM radio based on the PDCCH decoding, provided the UE **252** can decode the PDCCH well before the end of the subframe. To enhance the PDCCH decoding time, the base station **251** can use the reduced search space for scheduling the UE **252** if the UE **252** has reported the in-device coexistence interference to the base station **251**.

In one exemplary implementation, the unified signaling process described above works in the manner as follows. The base station indicates to the UE **252** that it supports "interference reporting" and also configures number of component carriers (CCs) that can be considered for reporting in-device co-existence interference via a system information block or specified dedicated message. When the UE **252** detects in-device co-existence interference, the UE **252** decides whether to report the presence of in-device coexistence interference to the base station **251** or can itself handle the in-device coexistence interference. If the UE **252** reports the in-device co-existence interference to the base station **251** through measurement reports or any other message (IDC_IND). For example, the UE **252** reports the preference of a FDM or TDM solution per single carrier or a set of the carriers. If a TDM solution is indicated for any corresponding carrier, the UE **252** reports a gap pattern indicating UE availability/non-availability for UL/DL scheduling of data. As illustrated in step **504**, the UE **252** indicates subframes and corresponding HARQ reserved for LTE module operation in a bitmap or DRX parameters. Further, the UE **252** may also report the duration for which the above mentioned solution is applicable.

After receiving the measurement report or any other message (IDC_IND). The base station **251** decides whether to select FDM solution or TDM solution to resolve in-device co-existence interference. If the base station **251** selects a FDM solution, then the base station **251** deactivates a carrier if it is a secondary cell and reported as facing/causing in-device co-existence interference. Otherwise, the base station **251** performs handover if the component carrier is primary cell and the component carrier reported as facing/causing in-device co-existence interference.

Alternatively, if the base station **251** selects a TDM solution, then the base station **251** indicates subframes and corresponding HARQ processes reserved for the LTE module operations or DRX cycle parameters to the UE **252**. The subframes and corresponding HARQ processes or DRX parameters may be the same or modified version of the reserved subframes and corresponding HARQ processes or DRX cycle parameters previously communicated by the UE **252**. The base station **251** may indicate the above information in a bitmap based gap pattern or in DRX parameters derived from the UE reported HARQ bitmap or DRX parameters. In case the gap pattern (either bitmap or DRX parameters) is absent in the response received from the base station **251**, the UE **252** can assume that the gap pattern sent to the base station **251** is to be applied.

In order to synchronize the UE with above configuration parameters, the base station **251** can opt to initiate an intra-cell handover procedure and sends new configuration to the UE **252** in a handover message. Additionally, the base station **251** may provide a parameter corresponding to the validity of configuration to the UE **252** in the response from the base station **251**. In case the UE **252** does not report that the in-device coexistence interference is over, the UE **252** and the base station **251** use the validity timer to release the configuration related to in-device coexistence interference and then the normal operation starts. In case, the UE **252** wants to extend the validity of the configuration, the UE **252** can send a measurement report or other message (e.g. IDC_IND) including all the parameters (DRX cycle parameters, reserved subframes and corresponding HARQ processes, and affected frequencies).

Although the present embodiments have been described with reference to specific examples, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the various embodiments. Furthermore, the various devices, modules, selectors, estimators, and the like described herein may be enabled and operated using hardware circuitry, for example, complementary metal oxide semiconductor based logic circuitry, firmware, software and/or any combination of hardware, firmware, and/or software embodied in a machine readable medium. For example, the various electrical structure and methods may be embodied using transistors, logic gates, and electrical circuits, such as application specific integrated circuit.

GLOSSARY OF TERMS AND THEIR DEFINITIONS

SINR: Signal-to-noise plus interference ratio
RSRP: Reference Signal Received Power
RSSI: Received Signal Strength Indication
RNTI: Radio Network Temporary Identifier
TTI: Transmission Time Interval
DRX: Discontinuous Reception
PDCCH: Physical Downlink Control Channel
HARQ: Hybrid Automatic Repeat Request
LTE: Long Term Evolution
ISM: The Industrial, Scientific and Medical Radio Band
GNSS: Global Navigation Satellite Systems
BLER: Block Error Rate
FDM: Frequency Division Multiplexing
FDD: Frequency-Division Duplexing
TDM: Time Division Multiplexing
TDD: Time Division Duplexing
Wi-Max: Worldwide Interoperability for Microwave Access
UL: Uplink
DL: Downlink
IEEE: Institute of Electrical and Electronics Engineers.

What is claimed is:

1. A method of receiving a message associated with an in-device co-existence interference in a base station, the method comprising:

transmitting, to a user equipment, a configuration message indicating that the base station configures the user equipment to report on an in-device co-existence interference and receiving, from the user equipment, a message associated with the in-device co-existence interference, the message including one or more frequencies affected by a first radio frequency module of the user equipment and a pattern corresponding to a hybrid automatic repeat request (HARQ) process, wherein the pattern indicates one or more sub-frames to be abstained from using due to being affected by operation of the first radio frequency module;

identifying the one or more sub-frames to be abstained from using based on the pattern; and

receiving, from the user equipment, a new message associated with the in-device co-existence interference when there is no in-device co-existence interference,

wherein the in-device co-existence interference is between the first radio frequency module and a second radio frequency module of the user equipment.

2. The method of claim **1**, further comprising:

transmitting a scheduling pattern to the user equipment in response to receiving the message.

3. The method of claim **2**, wherein the scheduling pattern indicates discontinuous reception (DRX) parameters derived based on the message.

4. The method of claim **1**, wherein the pattern that indicates the one or more sub-frames to be abstained from using is represented in a bitmap.

5. The method of claim **1**, wherein the first radio frequency module is for an industrial, scientific and medical (ISM) radio band.

6. The method of claim **1**, wherein the second radio frequency module is for long term evolution (LTE).

7. The method of claim **1**, wherein the message includes a parameter associated with discontinuous reception (DRX).

8. A base station for receiving a message associated with an in-device co-existence interference, the base station comprising:

a memory; and

a processor coupled to the memory, wherein the processor is configured to:

transmit, to a user equipment, a configuration message indicating that the base station configures the user equipment to report on an in-device co-existence interference and receive, from the user equipment, a message associated with the in-device co-existence interference, the message including one or more frequencies affected by a first radio frequency module of the user equipment and a pattern corresponding to a hybrid automatic repeat request (HARQ) process, wherein the pattern indicates one or more sub-frames to be abstained from using due to being affected by operation of a first radio frequency module,

identify the one or more sub-frames to be abstained from using based on the pattern, and receive, from the user equipment, a new message associated with the in-device co-existence interference when there is no in-device co-existence interference,

wherein the in-device co-existence interference is between the first radio frequency module and the second radio frequency module of the user equipment.

9. The base station of claim **8**, the processor is further configured to:

transmit a scheduling pattern to the user equipment in response to the received message.

10. The base station of claim **9**, wherein the scheduling pattern indicates discontinuous reception (DRX) parameters derived based on the message.

11. The base station of claim **8**, wherein the pattern that indicates the one or more sub-frames to be abstained from using is represented in a bitmap.

12. The base station of claim **8**, wherein the first radio frequency module is for an industrial, scientific and medical (ISM) radio band.

13. The base station of claim **8**, wherein the second radio frequency module is for long term evolution (LTE).

14. The base station of claim **8**, wherein the message includes a parameter associated with discontinuous reception (DRX).

15. The method of claim **7**, wherein the parameter associated with DRX comprises a given point of time at which the first radio frequency module or the second radio frequency module operates the DRX.

16. The base station of claim **14**, wherein the parameter associated with DRX comprises a given point of time at which the first radio frequency module or the second radio frequency module operates the DRX.

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